The 5th International Conference on Coupled Thermo-Hydro-Mechanical-Chemical (THMC)

Simulation of Hydraulic Fracture Propagation in Heterogeneous Reservoir based on a Dual-Lattice Discrete Element Method

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Outlines

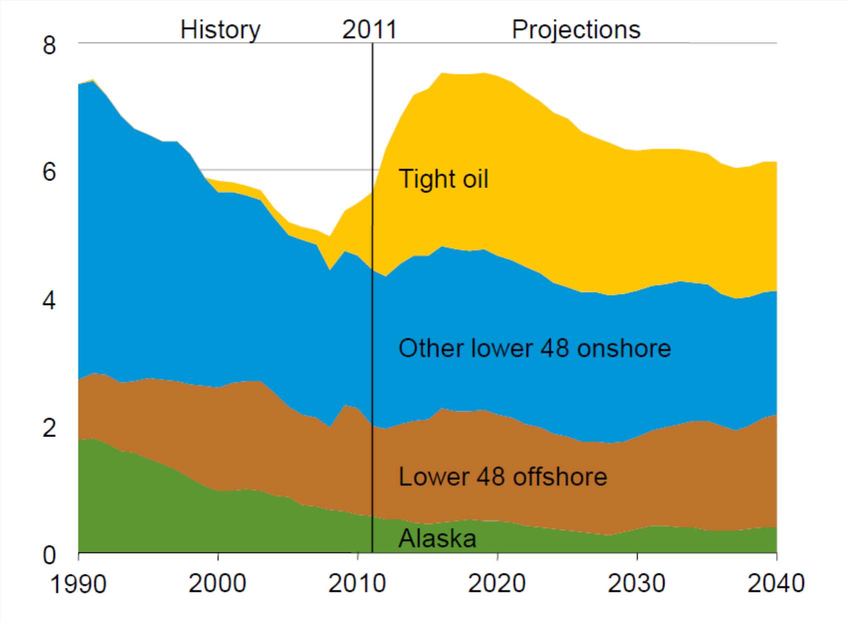
- Motivation
- Simulations Using Discrete Element Model
  - What is a Discrete Element Model?
  - What are the Advantages of DEM?
- Results
  - Multiple Fractures Propagation in Homogeneous Reservoir

    Effects of Viscosity and Rock Brittleness
  - Fracture Propagation in Heterogeneous Reservoir

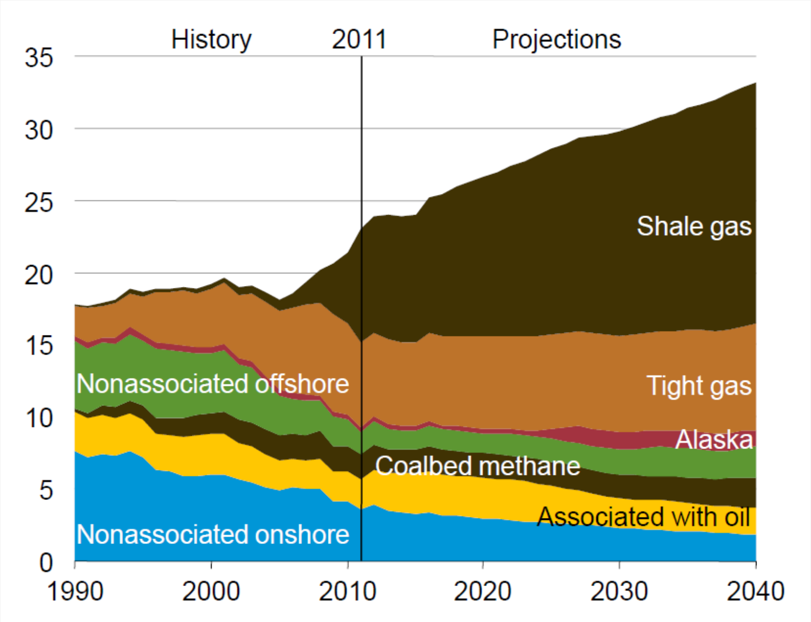
    Effects of Hydro and Mechanical Heterogeneity
- Conclusions

Motivation

Both the tight oil production and shale gas production exhibit a significant growth due to the successful horizontal wellbore and hydraulic fracturing technology.



U.S. domestic crude oil production by source



U.S. dry natural gas production by source

From 2013 Annual Energy Outlook - EIA

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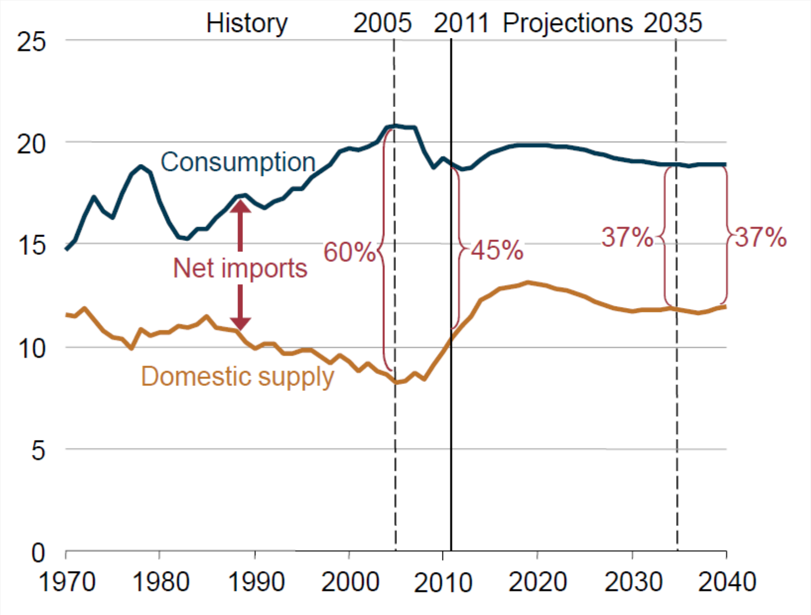
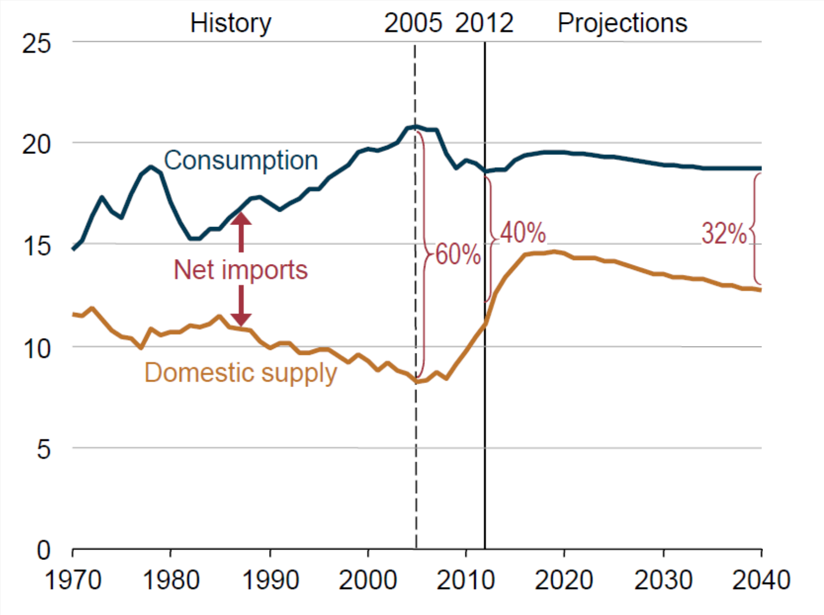
Motivation

U.S. liquid fuels supply, 1970-2040 (million barrels per day)



2013 Annual Energy Outlook - EIA

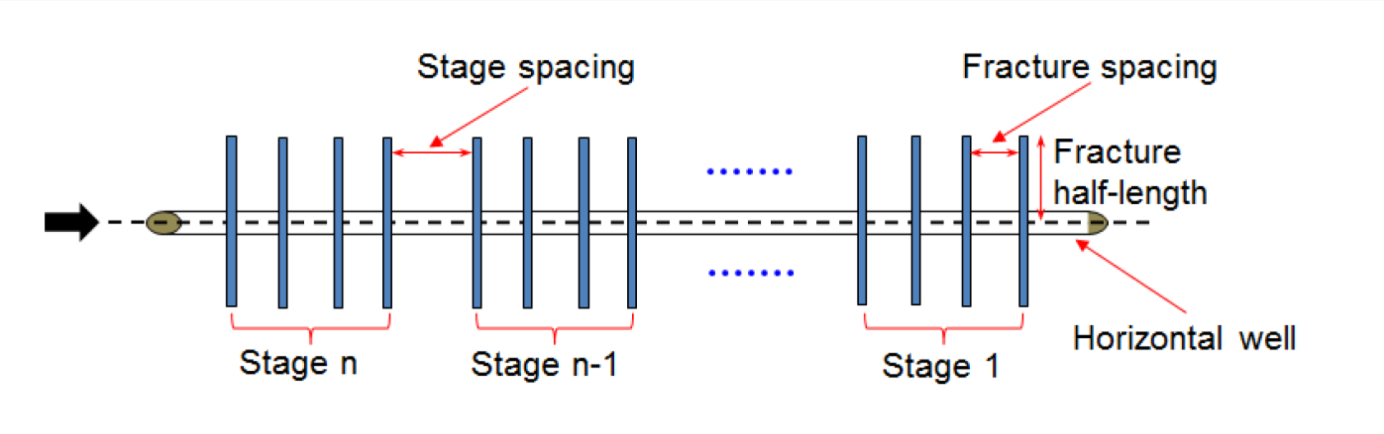


2014 Annual Energy Outlook - EIA

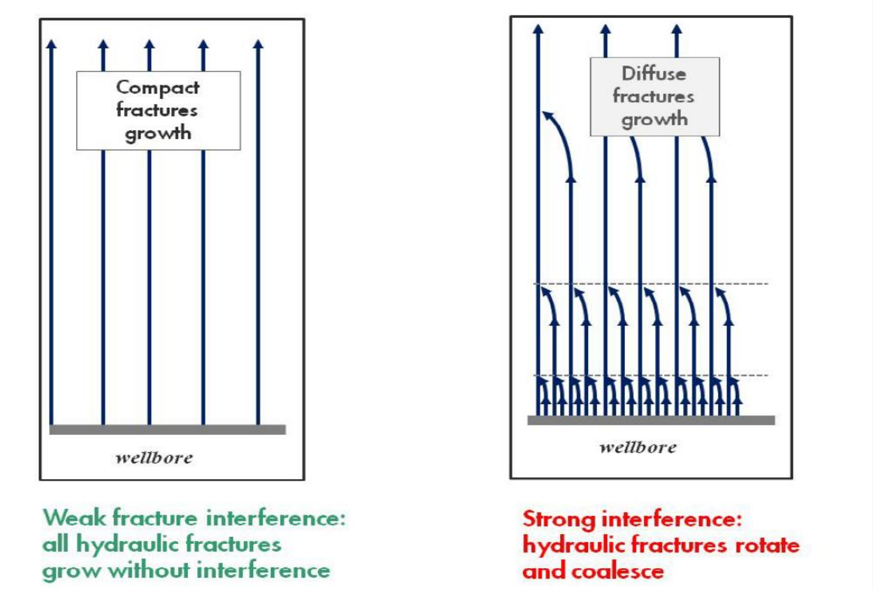
The net imports decrease from 37% to 32% due to the greatly increasing of domestic supply

Hydraulic Fracturing

Multi-stage Hydraulic Fracturing[1]:



Hydraulic Fracture Interaction[2]:



The conventional planar numerical model are insufficient to describe the induced hydraulic fracture geometry

1. *From Kan Wu Ph.D. Thesis 2014*
2. *SPE 163982 Sau-Wai Wong and et.al. 2013*

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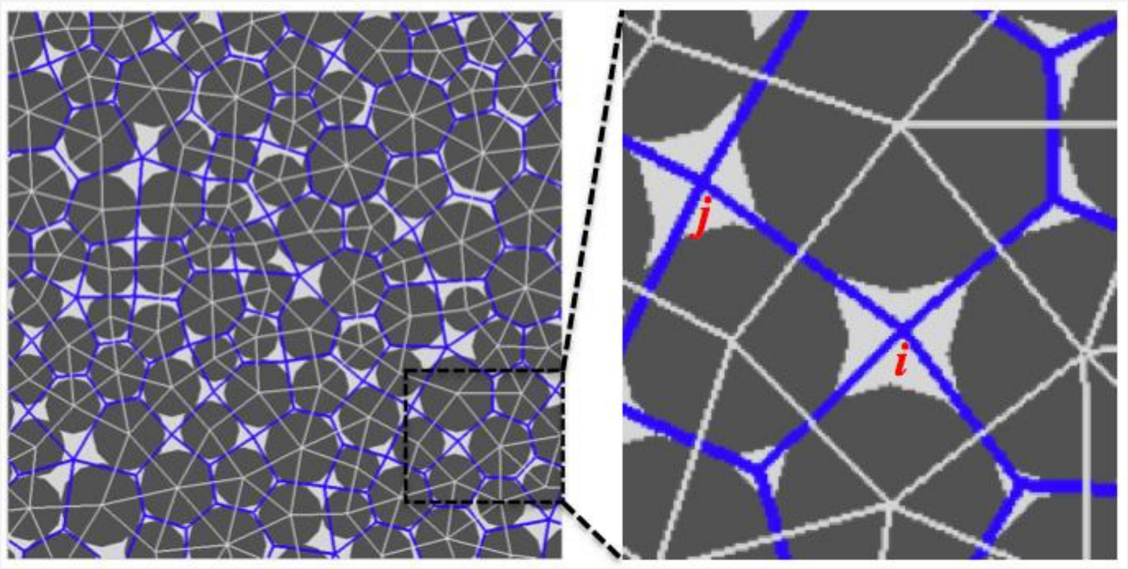
Discrete Element Modeling

A Non-planar Fracture Simulator Fully Coupling Geomechanics and Flow

Dual-Lattice:



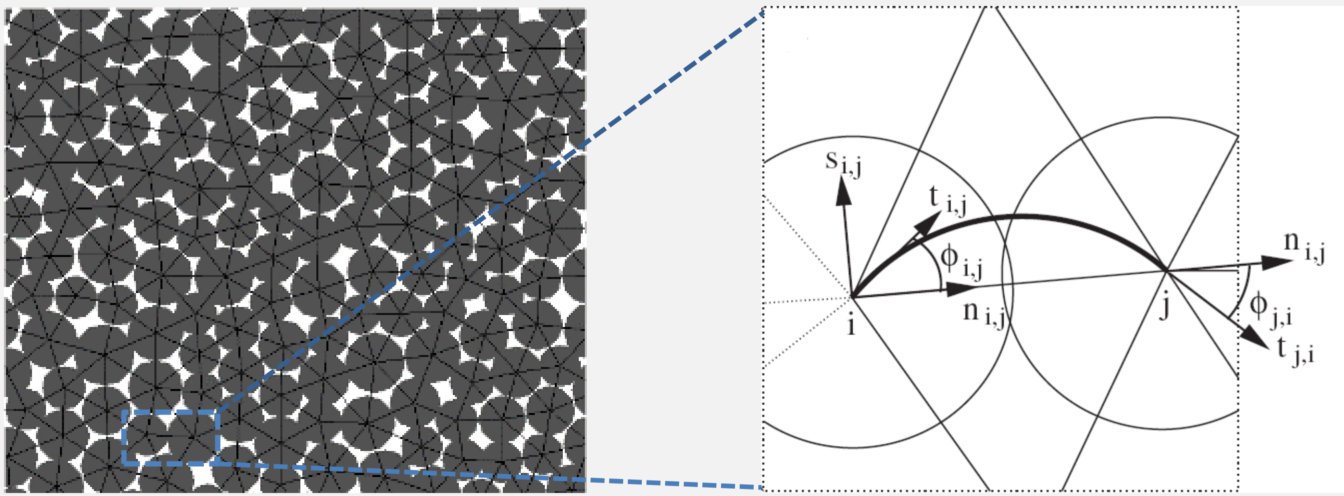
BLUE Lattice:
flow network

WHITE lattice:
DEM network

Rock is represented by circular / spherical particle cluster with finite mass

Discrete Element Modeling

A Non-planar Fracture Simulator Fully Coupling Geomechanics and Flow



- **The mechanical behavior of the rock is mimicked by the movements of particles and the status of connected beams.**
- **With the applied load, the beam between two particles will sustain increasing force which may lead to bond breakage and form microcracks.**
- **Continuing with the load, those microcracks may coalesce and become macroscopic fractures.**

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Advantages of Discrete Element Modeling

- Modeling hydraulic fracture propagation in homogeneous and heterogeneous reservoir environments
- Appropriate physical basis:
  - Fractures do not need to be defined a priori
  - Uses local, quantitative rock failure and fracture propagation criteria
  - Reliable representation of discontinuities
  - Poroelastic effects and fluid leakoff fundamentally included
- Captures fracture "merging" and "branching" effects
- Formally simulates interaction between hydraulic fractures and multiple natural discontinuities
- Formalized method for predicting transient microseismicity

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Hydraulic Fracturing in Homogeneous Reservoir

- Multiple fractures Propagation
- Effect of Viscosity
- Effect of Rock Brittleness

Reservoir Description

Homogeneous Reservoir

Size : 200ft × 200ft

Number of Perforation Clusters : 6

Perforation Spacing: 30 ft

Formation Permeability : 100 nd

Injection Rate: 50 bpm

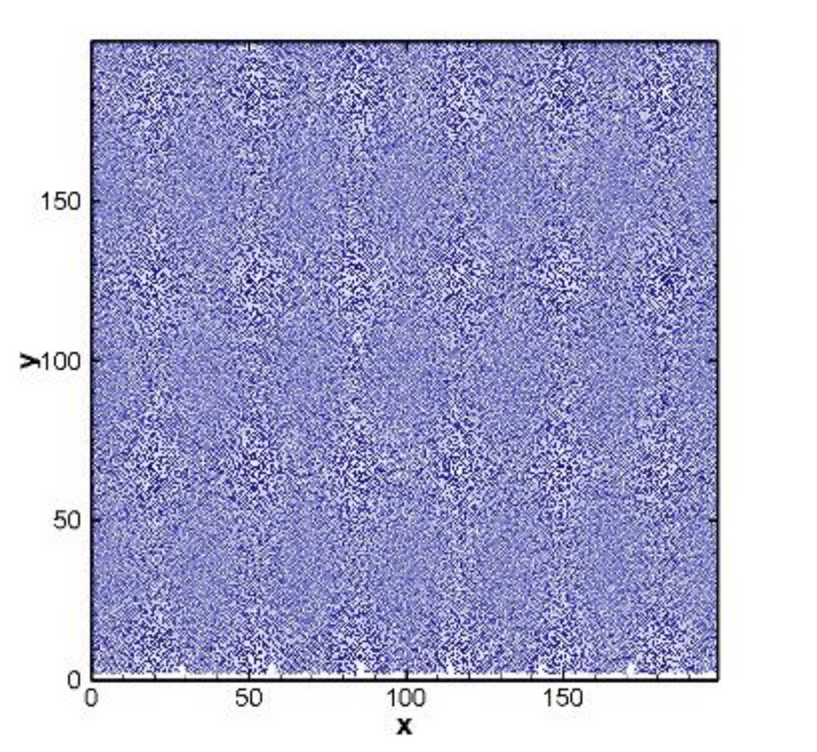
Young's Modulus : 40 GPa

Poisson's Ratio : 0.269

Maximum Horizontal Stress : 6961 psi

Shmin/Shmax = 0.5

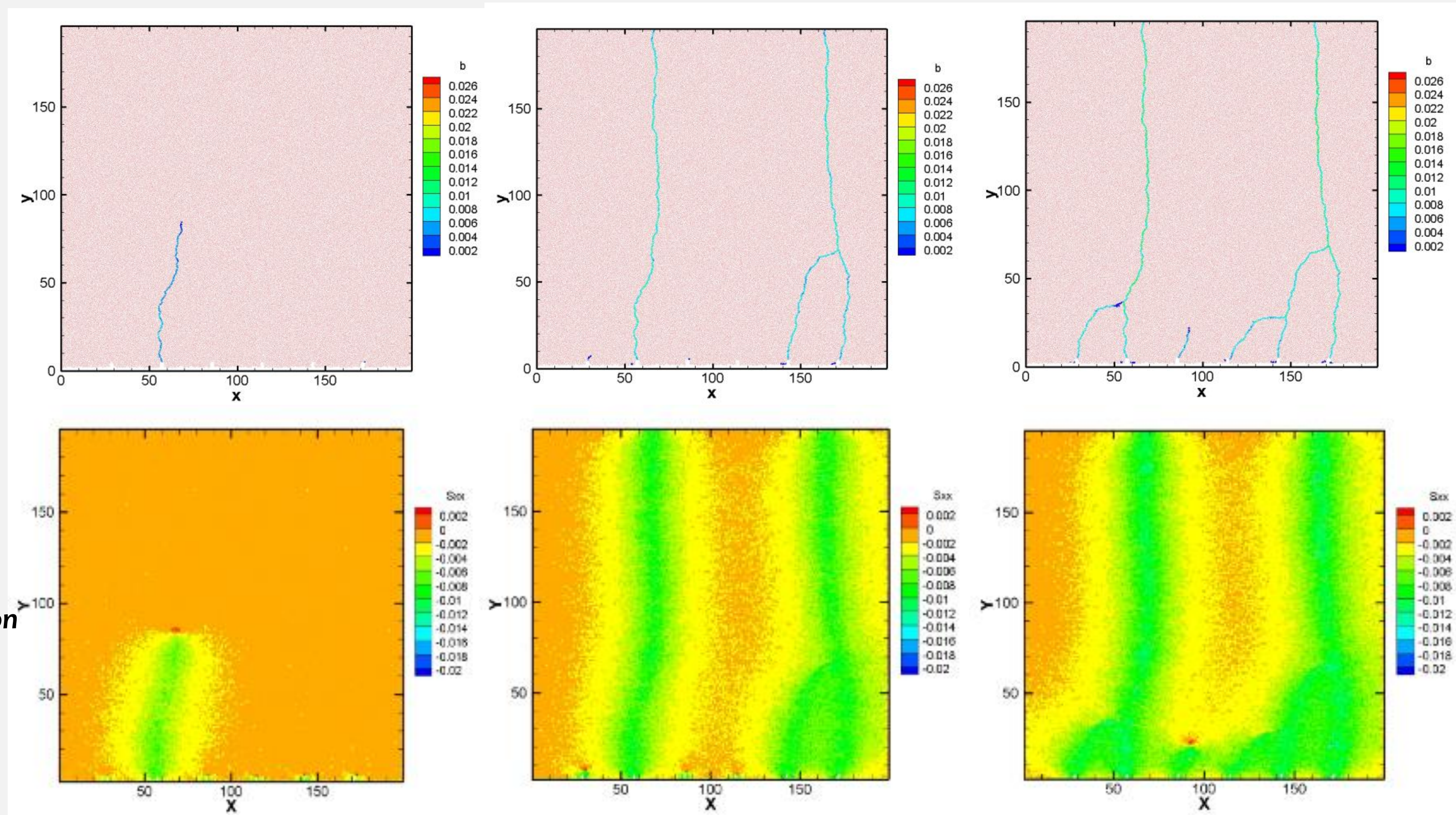
Injection Viscosity = 10 cp



Multiple fractures Propagation Simultaneously

Hydraulic Fracture Pattern

Stress Distribution



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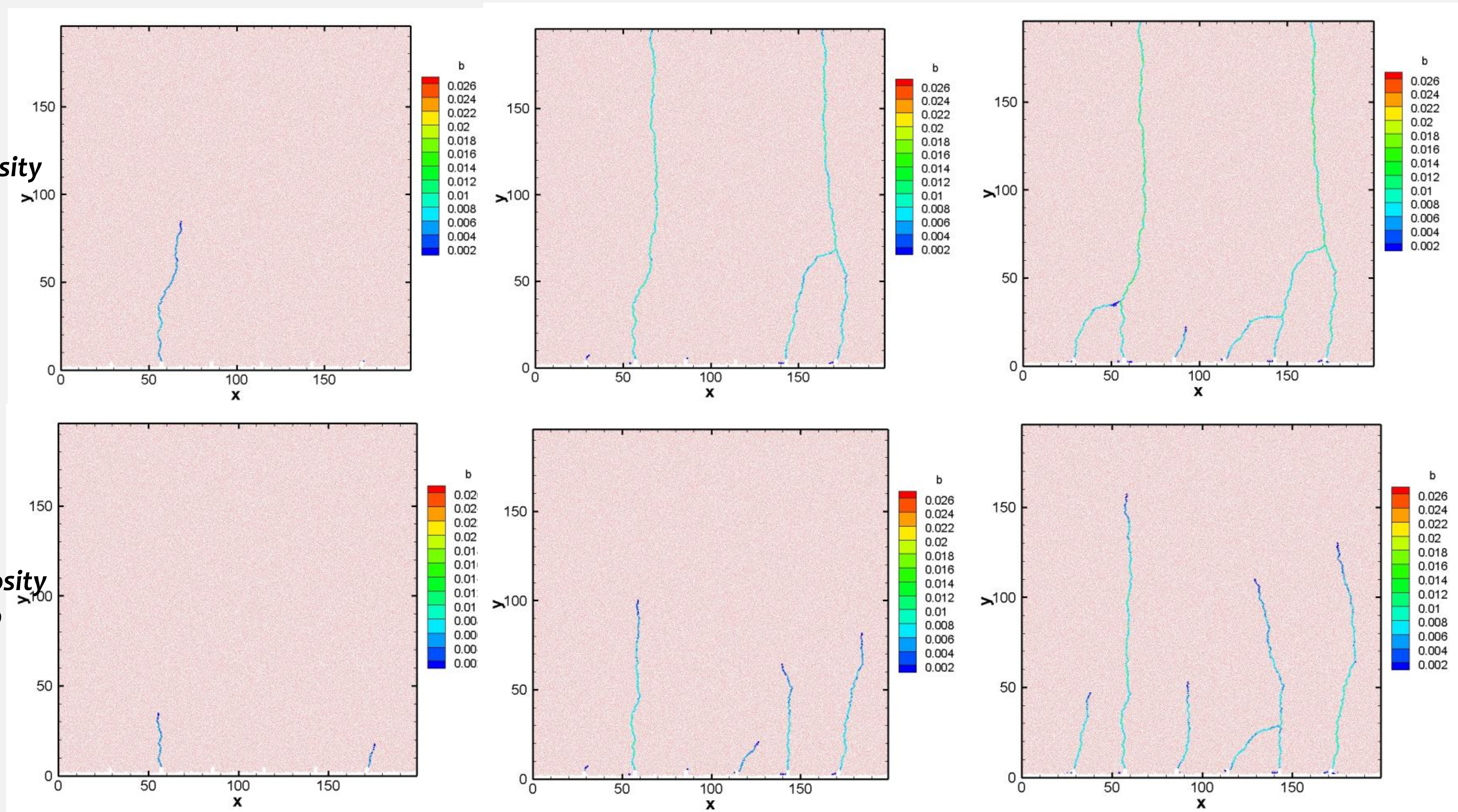
Multiple fractures – Viscosity Effect

Low Viscosity
μ = 10 cp

High Viscosity
μ = 800 cp

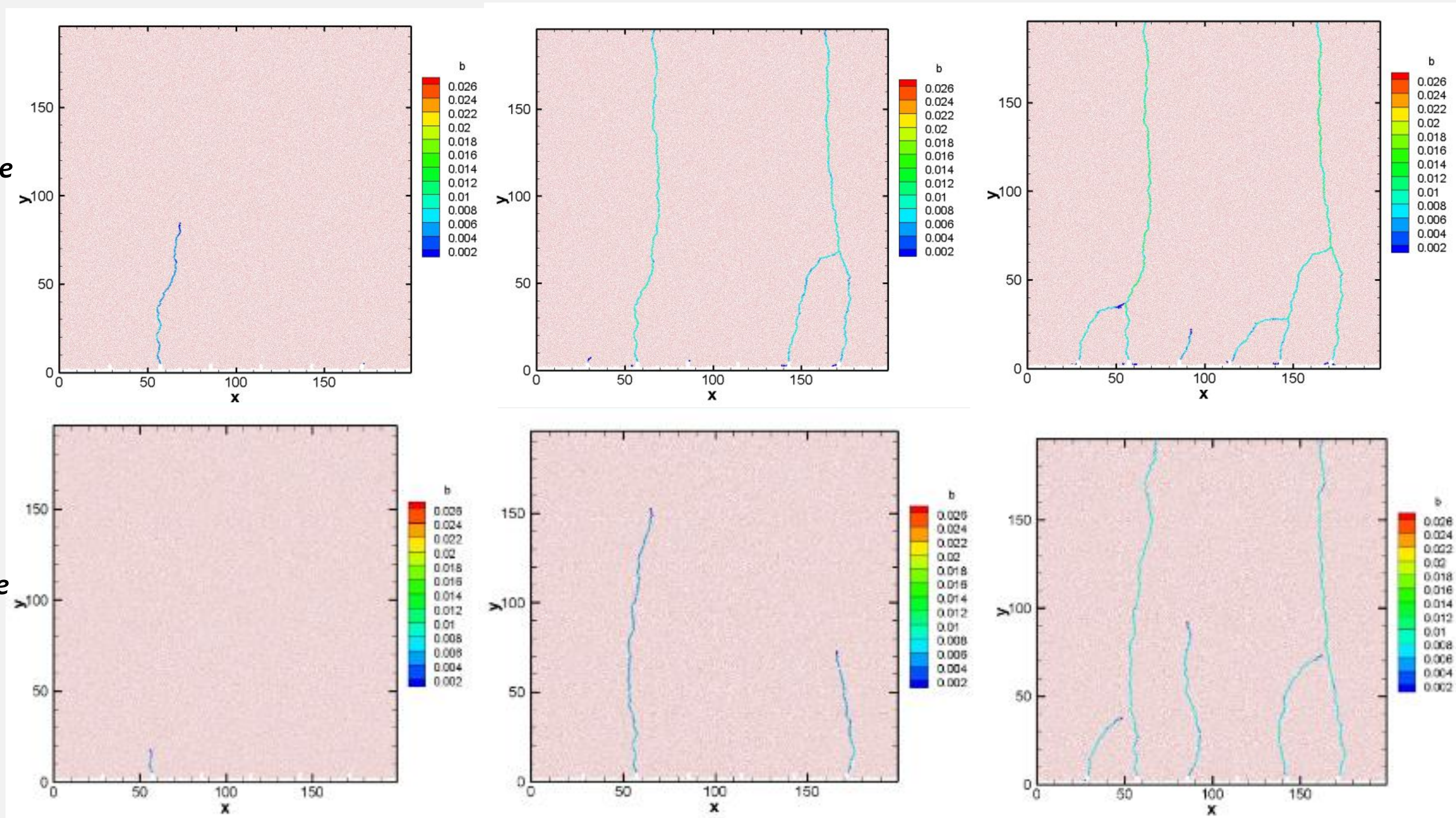


High viscosity injection will more easily induce multiple hydraulic fractures growing simultaneously

Multiple fractures – Rock Brittleness Effect

Very Brittle Rock

Less Brittle Rock



With smaller Young's modulus and larger critical strain, the less brittle rock is harder to break initially and is able to sustain larger stress.

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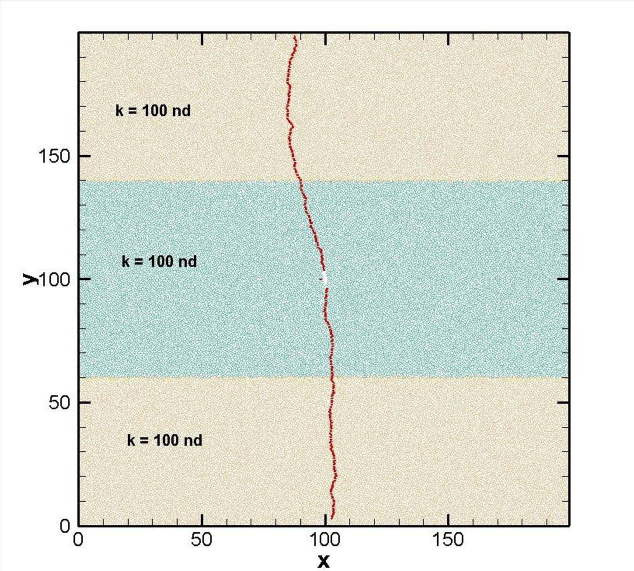
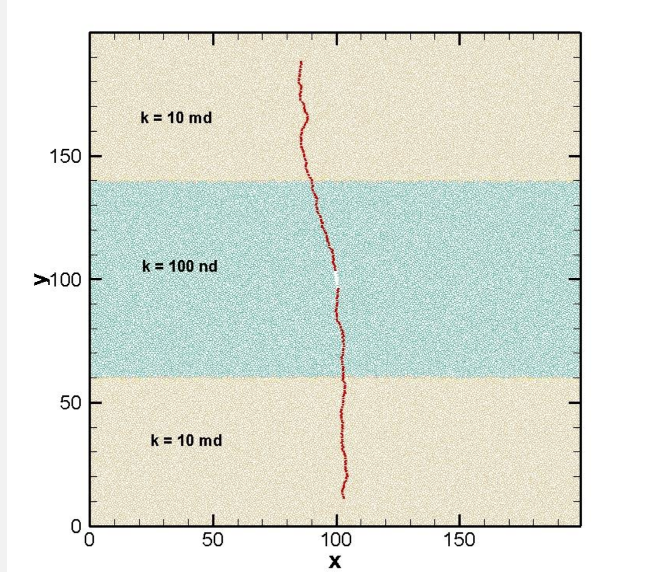
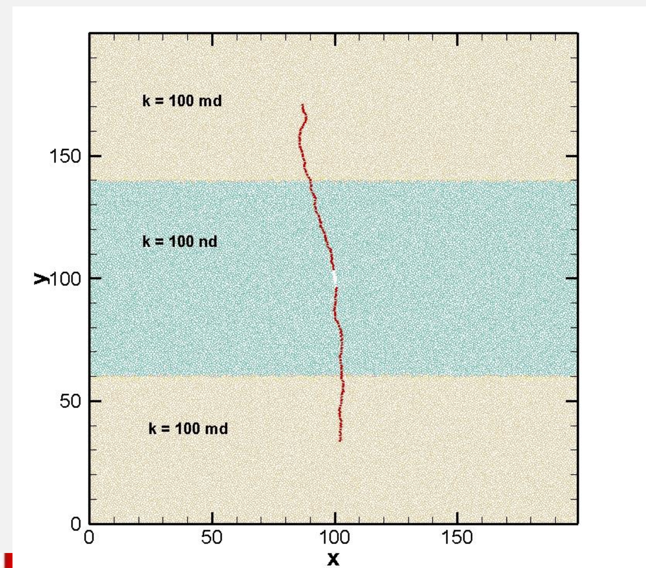
Hydraulic Fracturing in Heterogeneous Reservoir

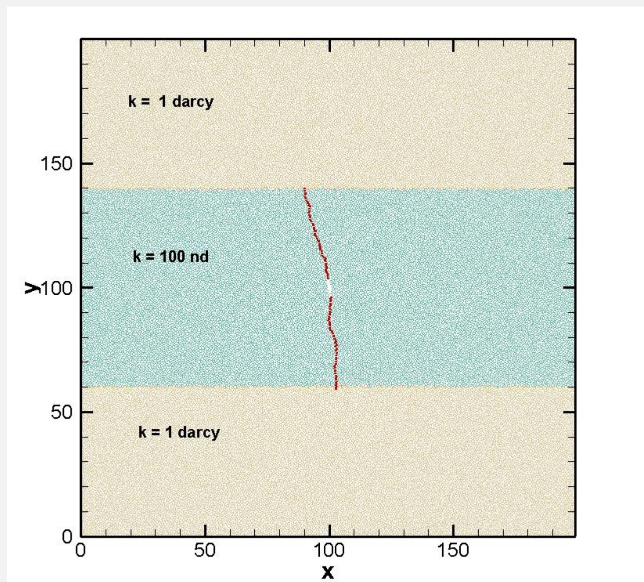
- Permeability Heterogeneity
- Rock Fabrics Heterogeneity

Permeability Heterogeneity





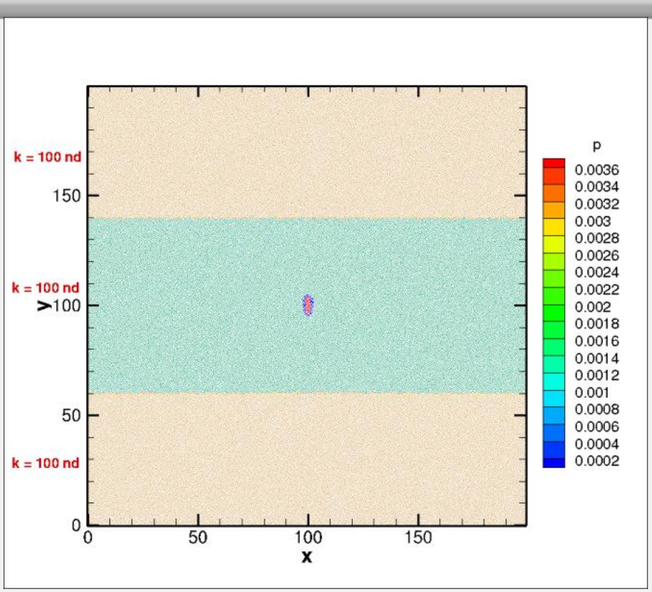


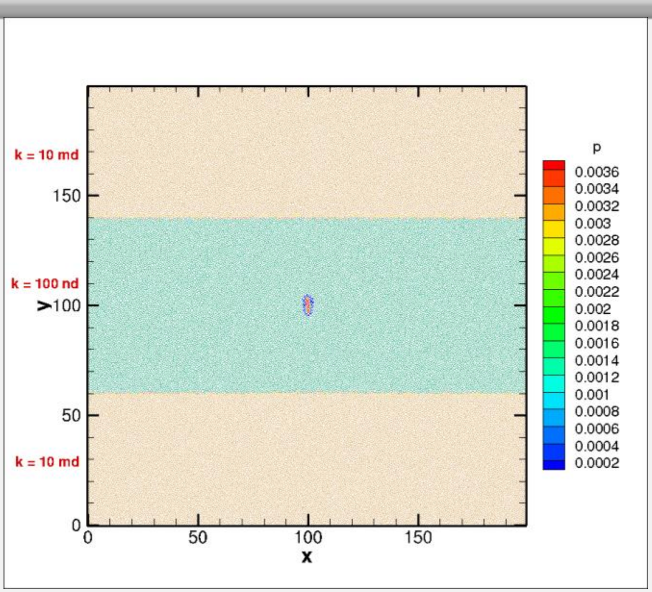


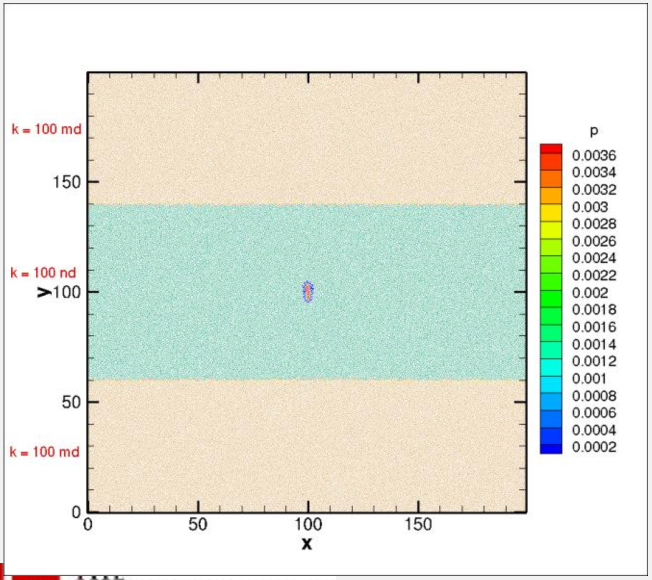
Fracture Aperture:

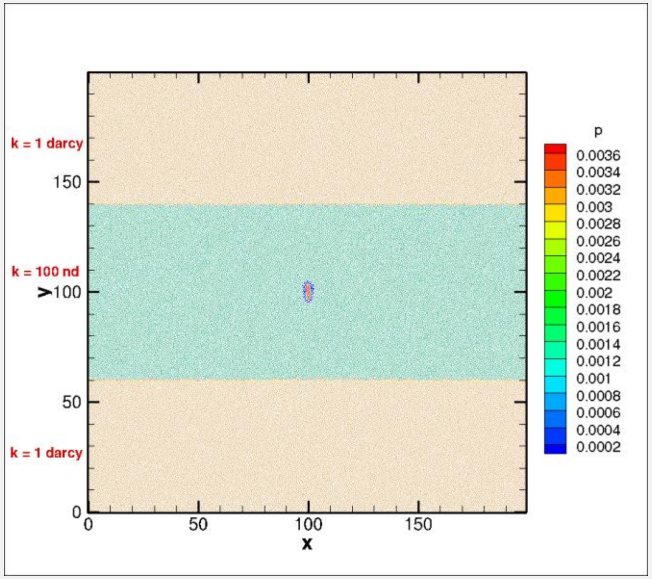
With the increasing of formation permeability, the hydraulic fracture has a gradually reducing propagated length

Permeability Heterogeneity





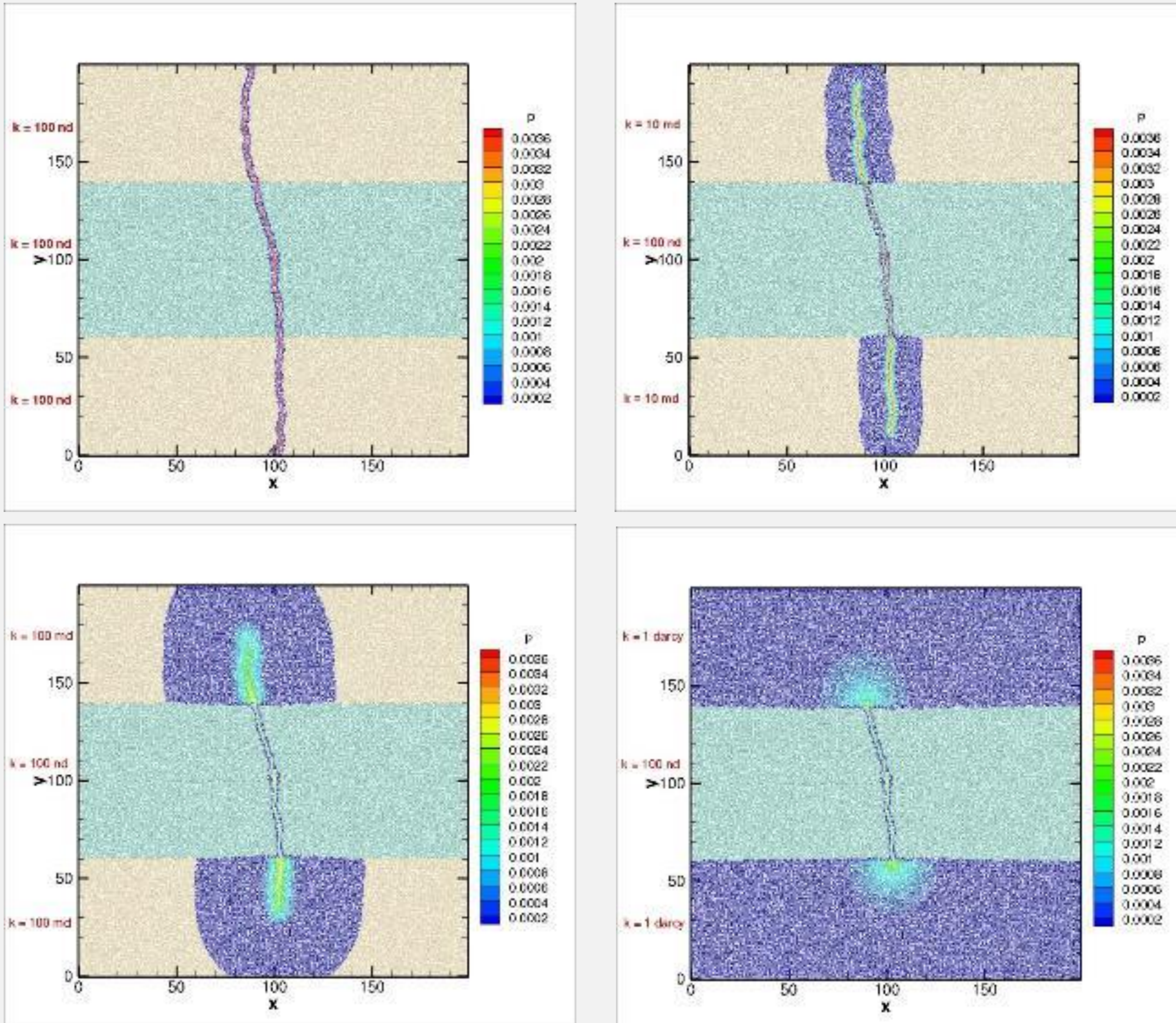




Net Pressure:

High permeability will make more injection fluid leak into the reservoir and result in large pressure loss along the fracture, therefore there is not enough pressure at the fracture tip to drive its opening

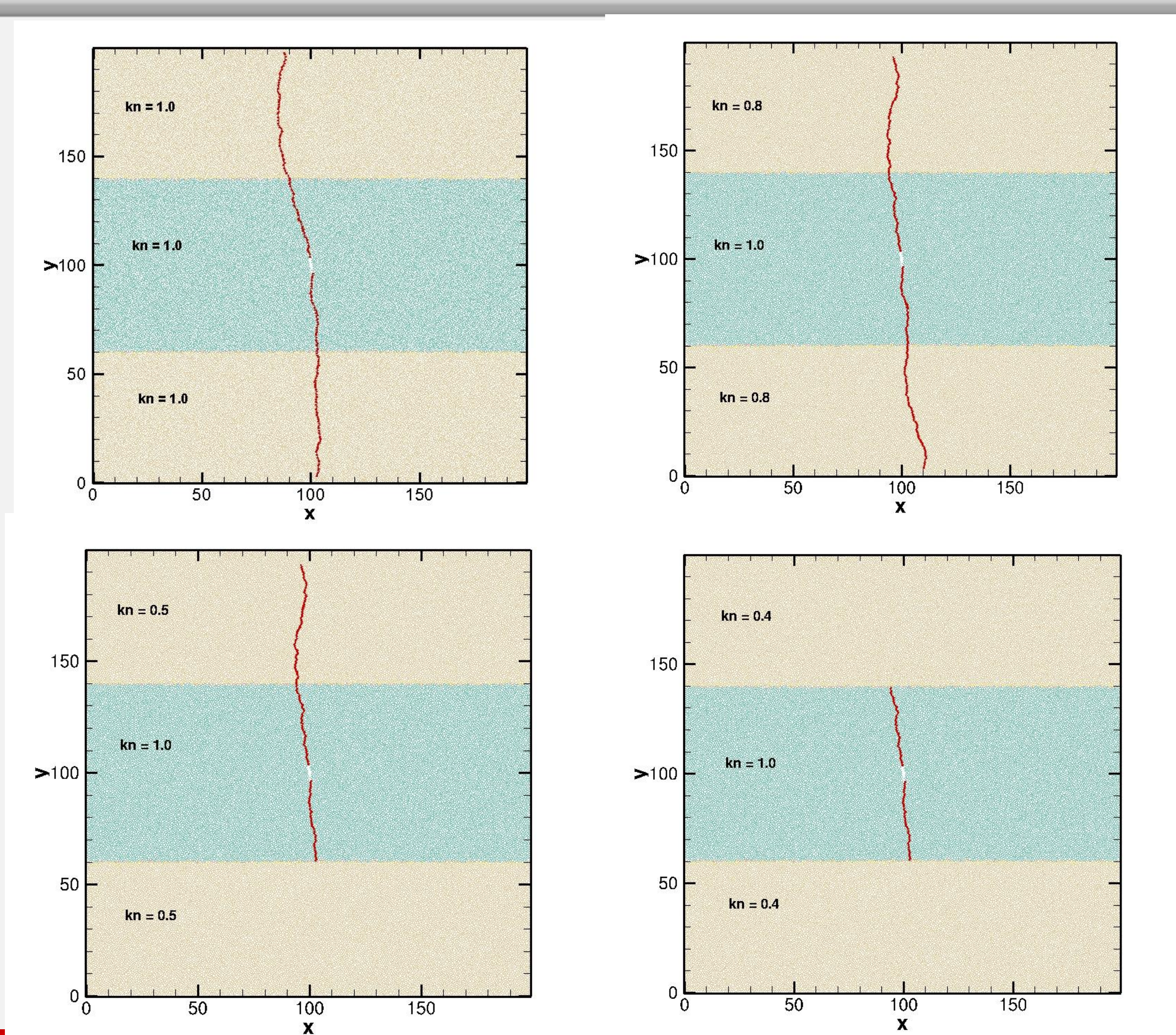
Permeability Heterogeneity



Fracture Aperture:

With the increasing of formation permeability, the hydraulic fracture has a gradually reducing propagated length

Rock Fabric Heterogeneity



Fracture Aperture:

Once the fracture grows into a less-brittle rock, the stress concentration near fracture tips is largely accommodated by nearby rock

The fracture may stop at the layer interface

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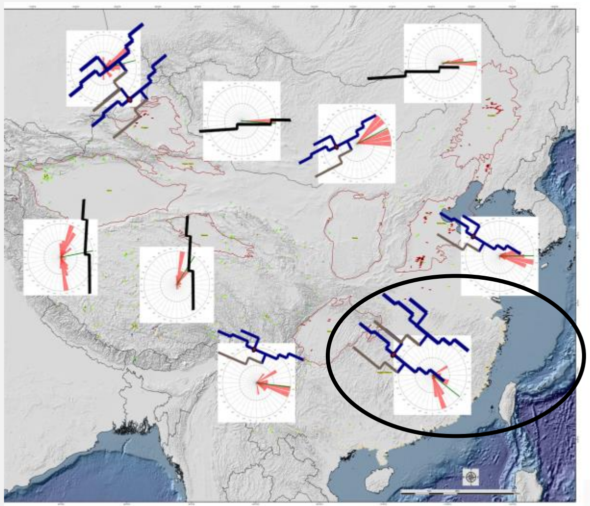
Rock Fabrics Heterogeneity

Mineral Name	Area %
Illite	51.67
Quartz	29.80
Plagioclase	6.57
Chlorite	2.60
Biotite	2.27
Glauconite	1.74
Other Silicates	1.48
Pyrite	0.84
Alkali Feldspar	0.68
Smectites	0.66
Unclassified	0.55
Particle Rims	0.51
Background	0.36
Other	0.20
Ankerite	0.14
Muscovite	0.12
Apatite	0.10
Rutile	0.04
Micrite	0.02
Dolomite	0.01
Zircon	0.00
Siderite	0.00
Calcite	0.00
Fe-oxides	0.00
Kaolinite	0.00

CS117R
Marine
L. Yangtze - Silurian
20µm Resolution



Rock fabrics and Mineralogy heterogeneity control:

Fracture propagation stops at the boundary between quartz rich and clay rich

19.9 µm
1000.0 µm

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Conclusions

- Lower viscosity will cause a relatively small number of fractures perforations to propagate initially.
- The opening of fractures will result in a stress shadow effect at the neighbourhood which will inhibit the growth of fractures from nearby perforations.
- Due to the reorientation of principal stress direction, the subsequent hydraulic fracture will be attracted to the preceding fracture.
- The high-viscosity injection fluid will increase the possibility for multiple fractures to grow simultaneously.
- Rock properties will affect the fracture pattern as well. The less brittle rock will make it difficult to break and is not favorable for hydraulic fracturing.
- Both high permeability and large critical tensile/shear strain will reduce the fracture propagation distance.

Thank you!
Questions?